Patent Claims

1. Method for producing substrates charged with materials, in which
   a) at least one substrate is introduced into an evacuated vacuum container;
   b) the surface of the substrate to be charged is exposed to a reactive gas which is adsorbed on the surface;
   c) the exposure of the surface to the reactive gas is terminated,
   d) the reactive gas adsorbed on the surface is allowed to react,
   characterized in that
   d_1) the surface with the adsorbed reactive gas is exposed to a low-energy plasma discharge with ion energy E_{I0} on the surface of the substrate of
   $$0 < E_{I0} \leq 20 \text{ eV}$$
   and an electron energy E_{eo} of
   $$0 \text{ eV} < E_{eo} \leq 100 \text{ eV};$$
   d_2) the adsorbed reactive gas is allowed to react at least with the cooperation of plasma-generated ions and electrons.

2. Method as claimed in claim 1, characterized in that the plasma discharge is realized with an ion energy E_{Io} on the surface of the substrate of
   $$0 \text{ eV} < E_{Io} \leq 15 \text{ eV}.$$

3. Method as claimed in one of claims 1 or 2, characterized in that the adsorbed reactive gas is a reactive gas mixture.

4. Method as claimed in one of claims 1 to 3, characterized in that the plasma discharge is maintained in an inert gas atmosphere.

5. Method as claimed in claim 4, characterized in that the plasma discharge is maintained in an argon atmosphere.

6. Method as claimed in one of claims 1 to 5, characterized in that the plasma discharge is generated in an atmosphere which contains a further reactive gas or gas mixture.

7. Method as claimed in claim 6, characterized in that the further reactive gas or gas mixture contains at least one of the gases hydrogen, nitrogen, oxygen.

8. Method as claimed in claim 6, characterized in that the further reactive gas or gas mixture comprises hydrogen, preferably is hydrogen.

9. Method as claimed in one of claims 1 to 8, characterized in that the vacuum container is evacuated to a pressure (p_v) for which applies:

$$10^{-11} \text{ mbar} \leq p_v \leq 10^{-8} \text{ mbar}.$$

10. Method as claimed in one of claims 1 to 9, characterized in that the reactive gas to be adsorbed is allowed to flow in up to a partial pressure p_p, for which applies:

$$10^{-4} \text{ mbar} \leq p_p \leq 1 \text{ mbar}.$$

11. Method as claimed in one of claims 1 to 10, characterized in that the gas adsorption rate on the surface is controlled by heating/cooling the surface.

12. Method as claimed in one of claims 1 to 11, characterized in that the exposure is terminated thereby that the substrate is transferred from the evacuated vacuum container into a further evacuated vacuum container.

13. Method as claimed in one of claims 1 to 12, characterized in that the exposure of the surface is terminated by pumping out the remaining adsorbed reactive gases from the evacuated vacuum container.

14. Method as claimed in claim 13, characterized in that the reactive gas is pumped out until a pressure p_v' is reached for which applies:

$$10^{-11} \text{ mbar} \leq p_v' \leq 10^{-8} \text{ mbar}.$$

15. Method as claimed in claim 1 to 14, characterized in that the substrate is exposed to the plasma treatment at least during a predetermined minimum time period.

16. Method as claimed in one of claims 1 to 15, characterized in that at least the steps b) to d_2) are completed at least twice.

17. Method as claimed in one of claims 1 to 16, characterized in that after carrying out at least one step d_2), a different material is applied onto the surface.

18. Method as claimed in claim 17, characterized in that the further material is applied by means of a vacuum coating process, by means of wet chemistry or galvanically.

19. Method as claimed in one of claims 1 - 18, characterized in that before the exposure of the surface to the reactive gas to be adsorbed, the surface is exposed to a low-energy inert gas plasma, preferably an argon plasma, with ion energies E_{I1} on the surface of

$$0 \text{ eV} < E_{I1} \leq 20 \text{ eV}$$

preferably

$$0 \text{ eV} < E_{I1} \leq 15 \text{ eV}$$

and an electron energy E_{e1} of

$$0 \text{ eV} < E_{e1} \leq 100 \text{ eV}.$$

20. Method as claimed in one of claims 1 - 19, characterized in that before the exposure of the surface to the reactive gas to be adsorbed, the surface is exposed to a low-energy plasma discharge in an atmosphere comprising a further reactive gas, where for the ion energy E_{I2} applies:

$$0 \text{ eV} < E_{I2} \leq 20 \text{ eV},$$

preferably

$$0 \text{ eV} < E_{I2} \leq 15 \text{ eV}$$

at an electron energy E_{e2} of

$$0 \text{ eV} < E_{e2} \leq 100 \text{ eV}.$$

21. Method as claimed in claim 20, characterized in that the further reactive gas is at least one of the gases hydrogen, nitrogen, oxygen.

22. Method as claimed in claim 20, characterized in that the further reactive gas comprises hydrogen, preferably is hydrogen.

23. Method as claimed in one of claims 1 - 22, characterized in that after the reaction of the adsorbed reactive gas, the surface is exposed to a low-energy inert gas plasma, preferably argon plasma, with an ion energy E_{I3} on the surface of

$$0 \text{ eV} < E_{I3} \leq 20 \text{ eV},$$

preferably

$$0 \text{ eV} < E_{I3} \leq 15 \text{ eV}$$

and an electron energy E_{e3} of

$$0 \text{ eV} < E_{e3} \leq 100 \text{ eV}.$$

24. Method as claimed in one of claims 1 - 23, characterized in that after the reaction of the adsorbed reactive gas, the surface is exposed to a low-energy plasma discharge in an atmosphere which comprises a further reactive gas, wherein for the ion energy E_{I4} on the substrate surface applies:

$$0 \text{ eV} < E_{I4} \leq 20 \text{ eV},$$

preferably

$$0 \text{ eV} < E_{I4} \leq 15 \text{ eV}$$

and with an electron energy E_{e4} of

$$0 \text{ eV} < E_{e4} \leq 100 \text{ eV}.$$

25. Method as claimed in claim 24, characterized in that the further reactive gas is at least one of the gases hydrogen, nitrogen, oxygen.

26. Method as claimed in claim 24, characterized in that the further reactive gas comprises hydrogen, preferably is hydrogen.

27. Method as claimed in one of claims 1 - 26, characterized in that the surface charging takes place by means of at least one of the following materials:

oxides or nitrides or oxinitrides of Si, Ge, Ti, Ta, Hf, Zr, Al, Nb, W and/or of the following metals:
Al, Ti, Cu, W, Ta.

28. Method as claimed in claim 27, characterized in that the surface charging takes place by means of at least one of the following materials:

silicon oxide, tantalum oxide, zirconium oxide, titanium nitride, tantalum nitride, tungsten nitride, $(TaSi)_xN_y$.

29. Method as claimed in one of claims 1 - 26, characterized in that all method steps are carried out in one vacuum container.

30. Method as claimed in one of claims 1 - 26, characterized in that the method steps are carried out in at least two vacuum containers.

31. Method as claimed in one of claims 1 to 30, characterized in that the process atmosphere encompassing the surface of the substrate during at least one of the phases comprised of steps b) and c) and/or d) to d_2), is isolated from the inner wall of a vacuum container at ambient surroundings.

32. Method as claimed in one of claims 1 to 31, characterized in that the surface to be charged includes the surface of a substrate already charged or coated.

33. Method as claimed in one of claims 1 to 32, characterized in that the surface before the adsorption step and/or after the reaction of the adsorbed reactive gases or gas mixture is exposed to a plasma-enhanced cleaning step, in which in a reactive gas or gas mixture - preferably comprising hydrogen - it is activated by means of a low-energy plasma discharge with ion energy E_r on the substrate surface of

$$0 \text{ eV} < E_r \leq 20 \text{ eV},$$

preferably

$$0 \text{ eV} < E_r \leq 15 \text{ eV}$$

at an electron energy E_{er} of

$$0 \text{ eV} < E_{er} \leq 100 \text{ eV}.$$

34. Method as claimed in claim 33, characterized in that during the at least one cleaning step the cleaning process atmosphere is isolated by means of a metallic encapsulation from the inside wall of the cleaning vacuum container

at ambient surrounding or this process atmosphere is directly preferably delimited by the inside wall of a cleaning vacuum container at ambient surroundings.

35. Method as claimed in one of claims 1 to 34, characterized in that through a single sequence of steps a) to d_2) one atom monolayer is applied onto the surface.

36. Method as claimed in one of claims 1 to 35, characterized in that by repeating steps b) to d) an epitaxial layer is grown on, with a change of the reactive gas heteroepitaxial ones, without a change of the reactive gas homoepitaxial ones.

37. Method as claimed in one of claims 1 to 36, characterized in that after carrying out a predetermined number of passes through steps b) to d) sequentially on several substrates the process volume of the vacuum container is subjected to a plasma-enhanced process volume cleaning step without an introduced substrate or with a substrate dummy, which process volume cleaning step preferably first comprises an etching step, subsequently a cleaning step, preferably in a plasma comprising hydrogen, inert gas or a mixture thereof.

38. Method as claimed in one of claims 1 to 37, characterized in that before step a) and/or after step d_2) the substrate is subjected to a substrate cleaning step after being spatially separated from the vacuum container and that the transport of the substrate there between is carried out under vacuum.

39. Method as claimed in claim 38, characterized in that the transport under vacuum takes place at least piecewise linearly or preferably along a circular path, with linear guide movements to said containers, preferably with motion components radial with respect to a circular path.

40. Method as claimed in one of claims 1 to 39, characterized in that during steps b) to and including d) the process atmosphere to which is exposed the surface is isolated from the inner wall of a vacuum container at ambient surrounding by means of a surface which in the new condition is chemically inert against the reactive gas or gas mixture and/or against a second plasma-activated reactive gas or gas mixture, preferably by means of a dielectric or graphitic surface.

41. Method as claimed in claim 40, characterized in that the inert surface is the surface of a partition wall which is spaced apart from the inner wall of the vacuum container along predominant surface sections.

42. Method as claimed in at least one of claims 40 or 41, characterized in that the surface for isolation in the new condition is realized of at least one of the following materials:
quartz, graphite, silicon carbide, silicon nitride, aluminum oxide, titanium oxide, tantalum oxide, niobium oxide, zirconium oxide or a layered combination of these materials, in this case also with diamond-like carbon or diamond.

43. Method as claimed in one of claims 1 to 42, characterized in that the plasma discharge is realized with an electron source with electron energy $E_e \leq 50$ eV, in particular preferred by means of a DC discharge.

44. Method as claimed in one of claims 1 to 43, characterized in that the plasma discharge is realized by means of a thermionic cathode, preferably with a directly heated thermionic cathode.

45. Method as claimed in one of claims 1 to 44, characterized in that in the process volume of the vacuum container for the plasma discharge at least two anodes spatially offset and preferably each heatable are provided, preferably each electrically actuatable separately and through the control of the electric potentials impressed thereon and/or their temperature the plasma density distribution along the surface is dynamically adjusted or controlled along the surface.

46. Method as claimed in one of claims 1 to 45, characterized in that during step d) in the process volume a magnetic field is generated and by means of this magnetic field the plasma density distribution along the surface is stationarily and/or dynamically adjusted or controlled, preferably at least such that it wobbles locally.

47. Method as claimed in one of claims 1 to 46, characterized in that at least the reactive gas or gas mixture to be adsorbed is allowed to flow distributively into the process atmosphere, preferably with a direction of inflow substantially parallel to the surface and, further preferred, with injection sites equidistant from the surface.

48. Method as claimed in one of claims 1 to 47, characterized in that the substrate is a silicon oxide-coated substrate with grooves sunk into the silicon oxide layer, and that after carrying out n-times one of the steps d_2), copper is deposited in the grooves, where $n \geq 1$.

49. Use of the method as claimed in one of claims 1 - 48 for the production of relaxed buffers.